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COMPARISON OF TWO FIRE TRUCK TURRET CONTROL SYSTEMS

JANUARY 1976

FINAL REPORT

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DOD AIRCRAFT GROUND FIRE SUPPRESSION AND RESCUE OFFICE
Wright-Patterson Air Force Base, Ohio 45433

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Eight Air Force fire fighting instructors performed a variety of tasks using a standard turret control system (a manually operated, hydraulically assisted system) and a newly designed electro-hydraulic hand held remote turret control system. The non-fire tests, demanding speed and accuracy, were negotiated significantly better with the new remote system. However, neither system outperformed the other in the fire tests. Perceptual problems caused by the fire and smoke limited operator performance, especially when using the new remote system.

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FOREWORD

This technical report describes a work effort conducted in pursuance of improved foam systems technology under the DOD Program Task of Agents and Agent Systems. The specific work objective was to determine whether an electronically controlled turret system could improve the aircraft crash fire fighter's efficiency. A human factors evaluation of an electronically controlled turret system was performed by the Air Force. The turret control system was designed and fabricated under contract to the Air Force by the Wichita Division, Boeing Company. The evaluation was conducted under the auspices of the Human Factors Branch, Directorate of Crew and Aerospace Ground Equipment, Deputy for Engineering, Aeronautical Systems Division, Wright-Patterson AFB, Ohio. Fire training facilities and personnel at the Air Force's School of Applied Aerospace Sciences (USAFSAAS), Chanute AFB, Illinois were made available by the Air Training Command for the conduct of the test program. Major William G. Bennett served as the Program Office project monitor. Testing was conducted during June 1975.

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INTRODUCTION

The development of a new fire fighting foam, Aqueous Film Forming Foam (AFFF), has dramatically altered fire fighting methods. Prior to the development of AFFF a fire was best fought by applying large amounts of protein foam about the cockpit. A path from the fire perimeter to the cockpit was then formed. Rescuers would approach the cockpit via the path of foam, remove the pilot and other crew members, and exit again via that path. The remainder of the aircraft fire was brought under control following rescue.

AFFF is a much different fire fighting agent than protein foam. Given equal amounts of AFFF and protein foam, the AFFF will put out a much larger fire. Application of AFFF is best done by rapidly sweeping the turret stream over the entire fire area. If done properly a shower of AFFF will rain down upon the fire from the turret stream. After the AFFF decends flames will still be seen for a moment, but the fire is actually smothered. Protein foam application methods would waste much of the AFFF and not result in its best use.

Three basic problem areas appear to exist in the transition from non-AFFF agents to AFFF agents. One is existing turret control systems due to control and visibility characteristics may not provide operators with the capability to sweep a stream of foam across the fire area rapidly and accurately. Second, further training may be required to prevent the use of protein foam application techniques when using AFFF. Third, increased experience with AFFF in a fire situation may be needed to improve AFFF application methods. The momentary existence of flames over a smothered fire may be confusing and lead to over

application in specific areas.

A new electronic control system was designed and developed under USAF contract by the Boeing Company. The controller (Figure 1) consiscs of a base and single control handle. An agent stream interupt switch is located at the end of the handle. The controller is linked by a cable to a set of electro-hydraulic control valves located in the turret panel. These valves control the turret's lateral and vertical movement. The controller is shown mounted in front of the A/S32P-4 crash fire truck turret operator's position. In this location, it can be used by either right or left handed operators. The electronic control system has two rather unique features. First, lateral and vertical movement of the turret may be effected simultaneously. Secondly, the position of the control handle reflects at all times the relative position of the turret, i.e., the turret moves through the same path as the handle. When handle movement is stopped, the turret will remain in the same relative position until commanded to move again by displacing the control handle. The controller does not return to a neutral position as do some electronic controllers currently being used on fire fighting equipment.

The present study was designed to compare the control characteristics of the new electronic device and the standard one and to ascertain if changing the relative position of turret and turret controller would improve performance. The study was divided into two phases. Phase I was a no fire situation which tested the control characteristics of each with regard to increasing operator speed and accuracy and examined the effects of different operator viewpoints while using the portable controller. Each subject was required to use each

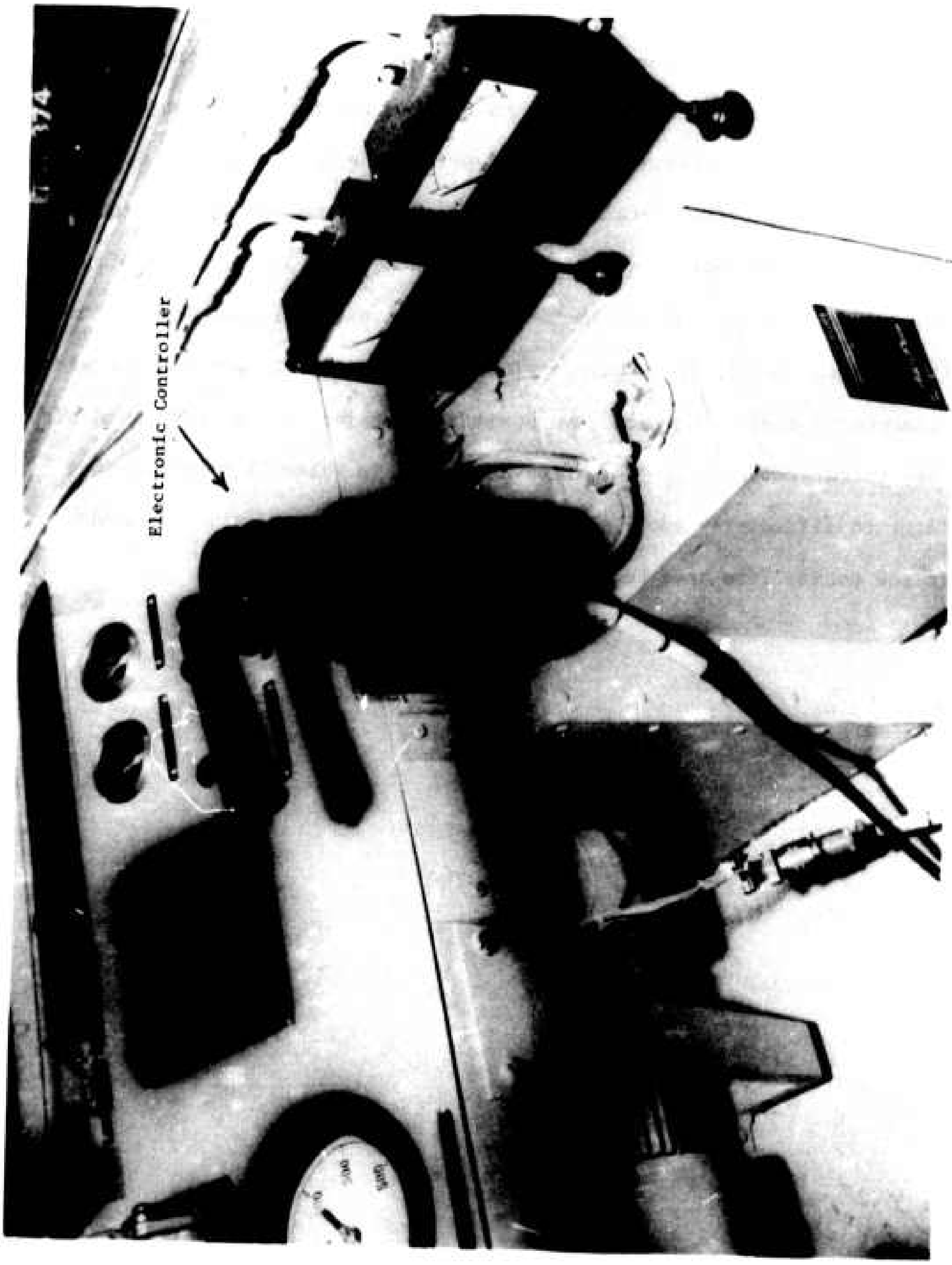

Figure 1

system to hit a track of 19 five gallon cans in a 5 second interval. The interval length (5 seconds) was such that a turret operator would have to track efficiently, yet not overly hastily, in order to hit all the cans as instructed. The cans were so aligned to require the turret stream to be moved laterally and longitudinally to negotiate the track. Phase II was a fire situation employing a standard size/intensity fire and was designed to compare both turret control systems. A set interval (13 seconds) of foam discharge was used in each of the four different operator positions. Two positions were used in the cab, one with the standard unit and another with the electronic control device. Two positions outside the cab were used with the new turret controller. The interval length in Phase II required an operator to efficiently apply the AFFF avoiding over application in order to cover the entire fire area before foam discharge ceased.

SECTION II

THE EXPERIMENT

1. APPARATUS

Two separate test grids were constructed. One grid was used for the tracking task and another for the fire tests. The tracking task grid was painted on a black-top parking area. The truck and turret operator positions are shown in Figure 2. The track was outlined with five gallon cans as shown in the figure. The fire test grid is displayed in Figure 3, and shows the fire truck turret operator positions and the metal mockup of a F-106 fighter. The fire test grid covered 5,070 square feet and had a gravel dike around its perimeter. The mockup was mounted on a hard clay surface covered by a one inch layer of charred gravel.

Two identical crash trucks were used for testing. One truck was a standard unit which contained a standard turret system. The standard turret system was operated via a lever extending down from the cab's ceiling. The driver and the occupant of the right front seat (position P1) had access to the lever. The lever was connected to a system of hydraulically operated servos which could rotate the turret laterally and vertically. The turret is designed so that water only or a mixture of water and aqueous-film-forming foam (AFFF) can be discharged through the turret's two foam barrels. Each foam barrel has a discharge capacity of 400 gallons-per-minute. The maximum range of foam discharge was approximately 180 feet.

The other truck was modified to accommodate the electrical turret control device developed by the Boeing Company. The electrical turret control device

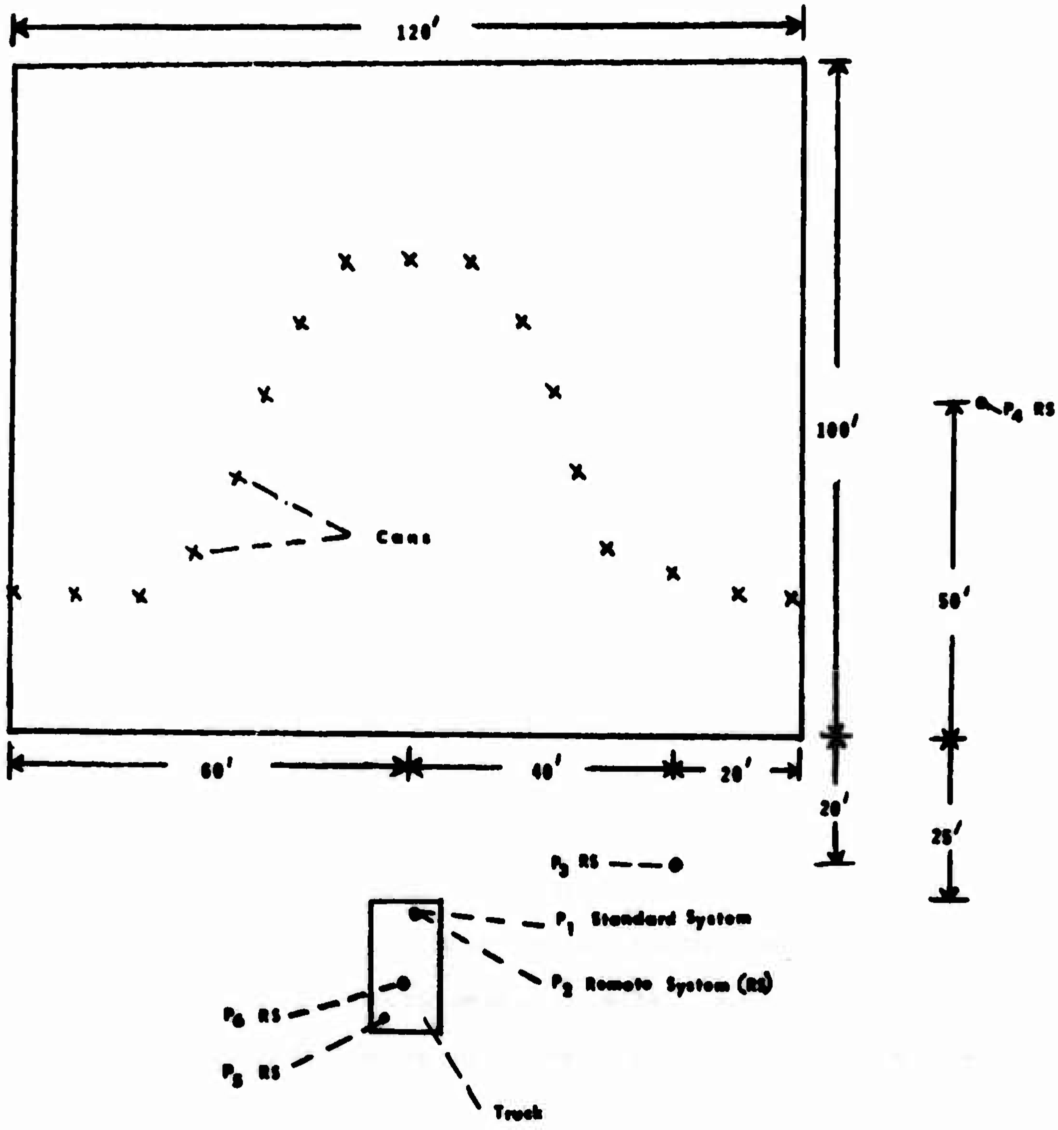

Figure 2: Tracking Grid

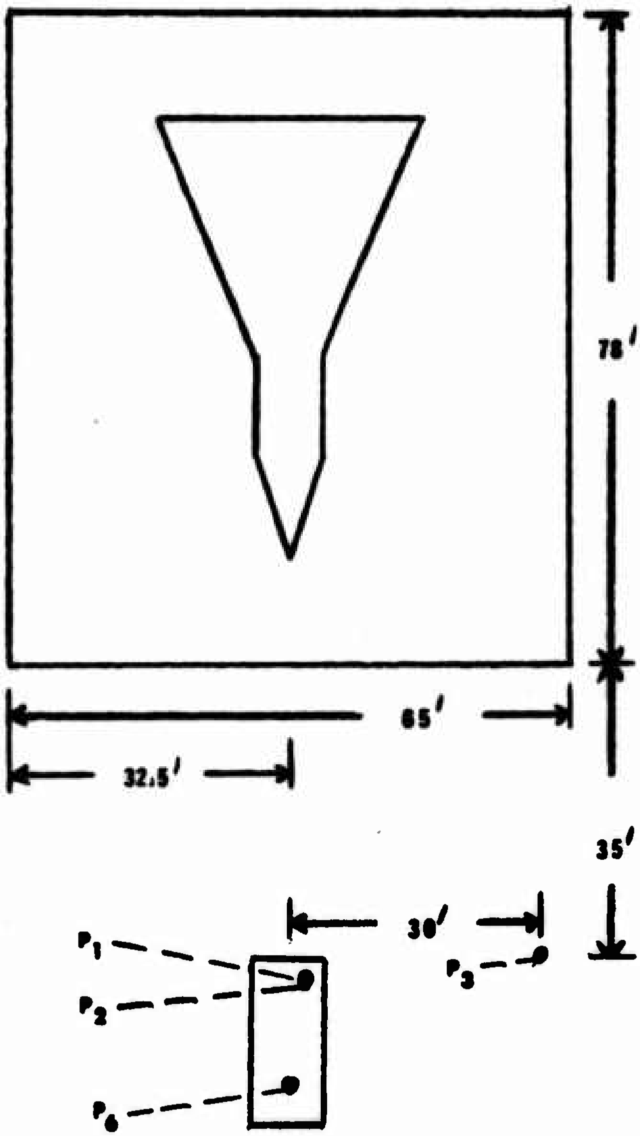

Figure 3: Fire Area

was connected to an electro-hydraulic servo system which operated the turret via an electric cable. The electrical turret control device (Figure 1) was mounted on the dash in front of the right seat, (position P_2 pictured in Figure 2). The device could also be removed from the dash mounting and placed on a movable tripod to positions P3, P4, and P6. Position P5 was located at the very rear and top of the truck, but was not used after Phase I practice because of the noise created by the diesel exhaust. The electrical turret control device gave no kinesthetic cues for turret position.

Data during Phases I and II were collected by photographing performance with a 35 mm data pack camera which took a still picture every 0.2 seconds. The camera and cameraman were lifted above the tracking grid and fire test area to a height of 40 feet by a hydraulic hoist mounted upon a separate vehicle. During Phase II, an additional camera (16mm movie camera) was mounted in a tower across the fire test area and used as an additional data source if smoke or camera malfunction eliminated the data pack camera as a data source.

2. SUBJECTS

The subjects were fire fighter instructors from the USAF Fire Fighting School located at Chanute Air Force Base, Illinois. Although testing began using nine (9) subjects, one individual departed prior to the completion of the test program. Therefore, the data considered in this report covers only that for the eight (8) individuals who completed the entire test program. Each subject participated in both Phases of the experiment.

3. PROCEDURE

The experiment was divided into two phases. Phase I was the tracking task and Phase II was the fire test. Phase I was accomplished first on the tracking grid. Each subject performed 12 practice trials and 10 test trials in the following order:

Practice

Right to Left (R→L)	Left to Right (L→R)	(R→L)	(L→R)
P1, P2, P3, P4, P5	P1, P2, P3, P4, P5	P6	P6

Test

L→R	R→L
P2, P1, P3, P4, P6	P6, P4, P3, P1, P2

The test director began each trial with a signal to the truck operator to start foam discharge. The turret operator (test subject) positioned the turret stream off the tracking grid to the far right or the far left before beginning the turret sweep for that trial. The test director then gave a second signal to the turret operator to begin tracking. Each turret operator was instructed to attempt to hit all of the cans in one sweep. Five seconds after the second signal the test director instructed the truck operator to cease foam discharge. The grid was then cleared and another trial begun. Testing was dependent upon weather conditions and was conducted only during dry and low wind conditions. Each subject filled out a questionnaire after each test trial (Appendix A).

Phase II was conducted after Phase I testing and used the same eight subjects. Each subject performed four practice trials with the standard turret control system and without fire to familiarize himself with the Phase II time sequence and foam dispersion pattern. Practice was not done with the electrical turret control device since it was unavailable and the fire fighters were already thoroughly familiar with its operational characteristics after Phase I. An area the size of the fire test grid was outlined with cans on the tracking task grid and the truck positioned as it would be on the fire test. Each subject was instructed to lay down foam in an "S" pattern starting from the left front of the grid and working laterally along the front perimeter and then back deeper into the fire area as shown in Figure 4.

The test director began each test or practice trial with a signal to the truck operator to begin foam discharge as the turret operator positioned the turret stream off to the left of the fire area. The second signal instructed the turret operator to begin applying agent to the fire area in the prescribed manner. After 11.5 seconds a third signal was given to the truck operator to cease foam discharge. The total time of foam discharge was 13.0 seconds. Each subject then filled out a questionnaire.

During the test trials each subject used the standard turret system (P1) first for one trial, and then used the electrical turret control system from the in-cab position (P2). Subjects 2, 4, 5, and 9 were selected at random to use the electrical turret control device from positions P3 and P6 (Figure 3). Each of the four subjects was dressed in fire protective clothing when using

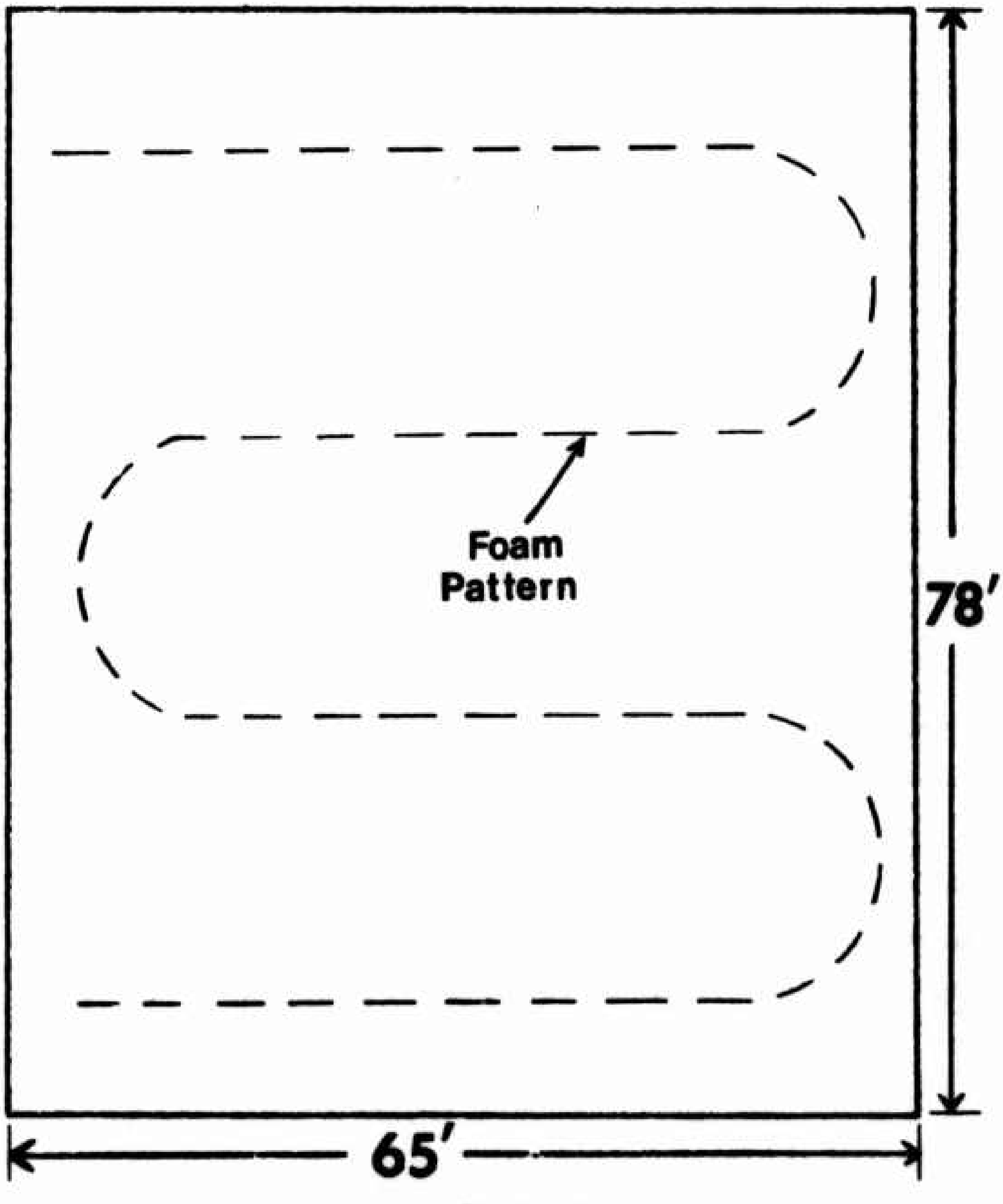

Figure 4: Fire Test Practice

the device at P3 and P6. Each used the device from P6 before using it at P3.

Each test fire used 900 gallons of JP-4 which was applied to the entire fire test area by two firemen using hand held hoses. The fuel was then ignited by a torch and allowed to burn for 45 seconds until the entire test area was aflame and at maximum intensity. After foam application the area was agitated by a stream of water from a crash truck. The agitation caused the flames to break through the foam layer and burn off the remaining foam. In about ten minutes the entire grid was aflame again and the AFFF agent was evaporated. The fire was allowed to burn out and no more agent was applied. Water was then used to cool the mockup area prior to preparing the area for another test trial. The entire process took approximately 45 minutes.

4. SCORING SYSTEM

The data from Phase I and II was scored independently by two scorers. The Phase I data were the photographs from the data pack camera, which took a still photo every 0.2 seconds. On each experimental trial photography began with the onset of foam discharge and ended with its cessation. For each trial, the data photo was the one that showed the tracking grid condition just after the alotted time interval for tracking had ended. Each scorer examined said photograph independently and noted the number of cans covered with foam. The two scores for each trial were then averaged to yield the score for that trial.

Scoring Phase II data also involved the photos from the data pack camera. The photo depicting the fire test area just after foam cessation was used as the data photo for that trial. A grid, which was composed of 16 equal sized blocks, was superimposed over each data photo. Each block represented 6.25% of the total area. Each scorer independently noted the number of blocks still filled with flame, multiplied by 6.25%, and thereby obtained the percent fire uncontrolled score, which was substracted from 100% to obtain the percent fire controlled score. The two scores for each trial were then averaged to yield the score for that trial.

SECTION III

RESULTS AND DISCUSSION

Analysis of the tracking task data from Phase I was done via a Friedman Two-Way Analysis of Variance.[1] Performances from P2, P3, and P6 were statistically equal and significantly superior ($p \leq .01$)[2] to performances from positions P1 and P4 (Figure 5). The experiment performances from P2, P3, and P6 demonstrates that the change perspective created by moving the portable turret controller to positions P3 and P6 was ineffectual in improving performance over that obtained by using it in the cab (P2). However, the change in perspective created by P4 caused the worst performance. Position P4 prevented the turret operator from accurately perceiving the direction, velocity, and point of impact of the turret stream. Such perceptual difficulties hindered accurate coordination of lateral and longitudinal turret movements making those cans in the center of the track hardest to hit. In comparing P1 and P2 visibility was not a factor since both were in-cab positions. The significantly poorer P1 performances demonstrate that the standard turret control system required more effort just to move the turret and was more difficult, once moving, to quickly alter its angle and direction. The result was that maneuvers that required the stream to be move laterally and longitudinally

1. Siegel, Sidney, Nonparametric Statistics For the Behavior Sciences, New York: McGraw-Hill Book Co, Inc., 1956, pp. 166-172.

2. The term "$p \leq .01$" indicates how reliable the differences were. Given 100 replications of the experiment, 99 of them would yield the same differences as the present experiment.

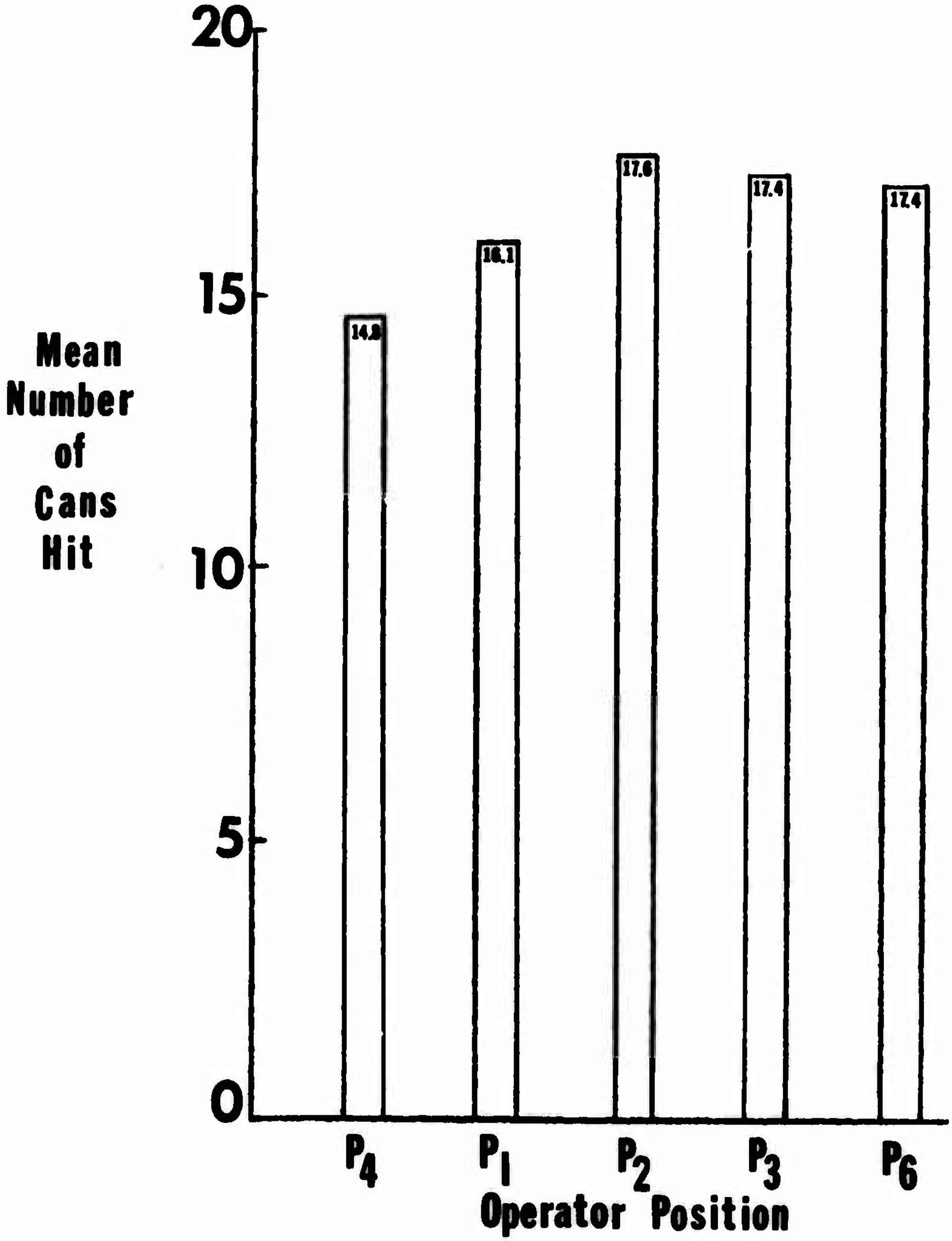

Figure 5: Phase I Performance

simultaneously were especially difficult.

Analysis of the fire test data obtained in Phase II showed no statistically significant differences (Figure 6 and 7). In Figure 7, the poorer P1 mean was caused by only one very poor score, which did not conform with the P1 performance trend. None of the positions or turret control systems significantly affected performance. It may be noted, however, that many of the performances were characterized by an over-application of foam on those portions of the fire test grid closest to the truck. It is estimated that about 75% of the foam was applied to about 50% of the area nearest the truck. Turret operators apparently needed to perceive the point of impact of the stream before advancing it faster and deeper into the fire area. This, combined with a momentary lapse between the smothering of the fire and the disappearance of the flames, perhaps inhibited them from advancing the stream faster. Thus, time expired prior to full fire control.

The questionnaire data from both phases revealed a preference for the electrical turret control device. Ninety-four percent and 82% of the ratings from Phase I and II respectively, cited preference for the electrical turret control device. Apparently the preference for the electrical device created during Phase I continued through Phase II.

Although the electrical turret control device facilitated speed and accuracy as shown in Phase I, the actual fire situation posed problems not solved by increasing the control system's flexibility. If a turret control system, by virtue of controller position alone, would give the operator an accurate impression of the turret stream's point of impact, then being able

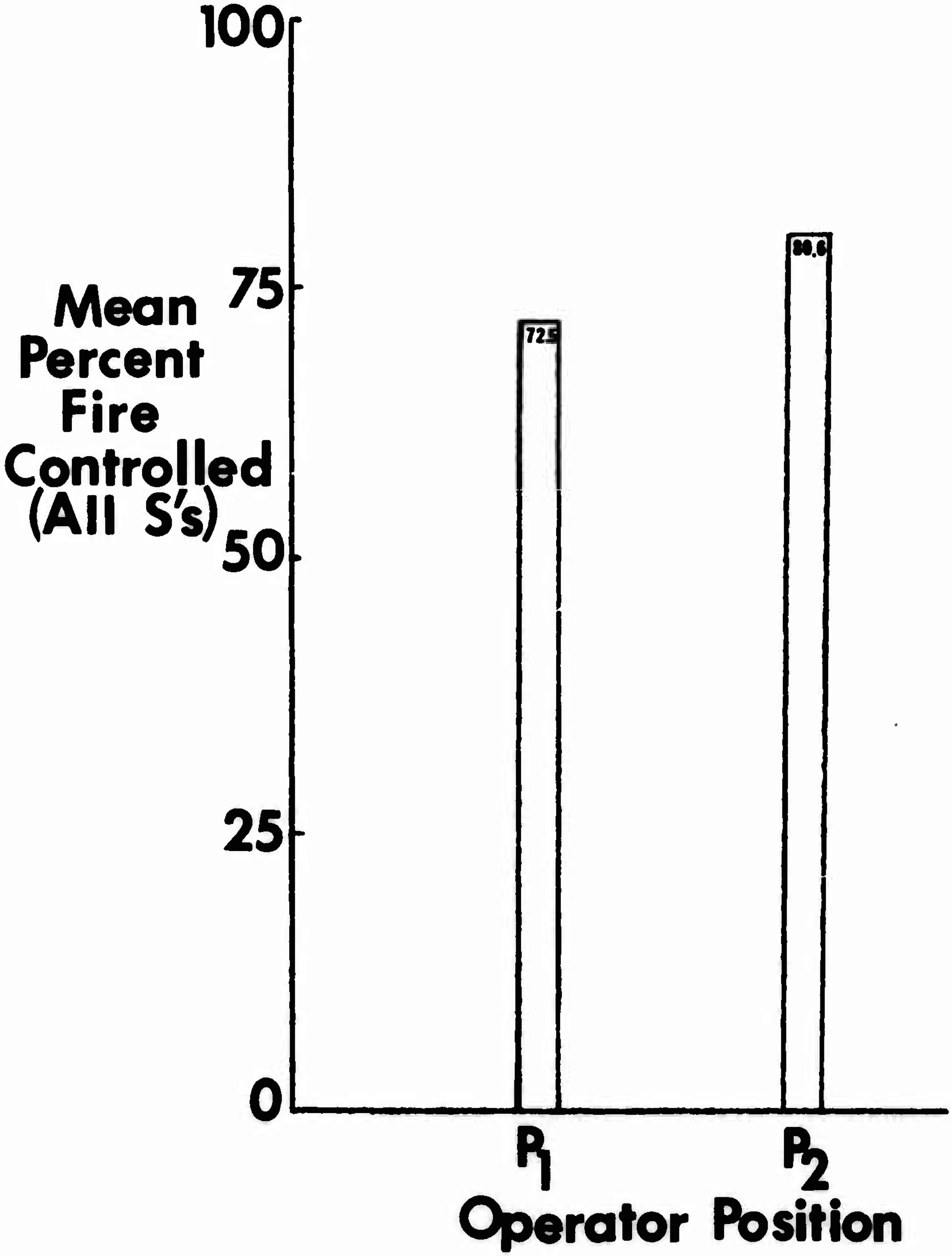

Figure 6: Phase II Performance

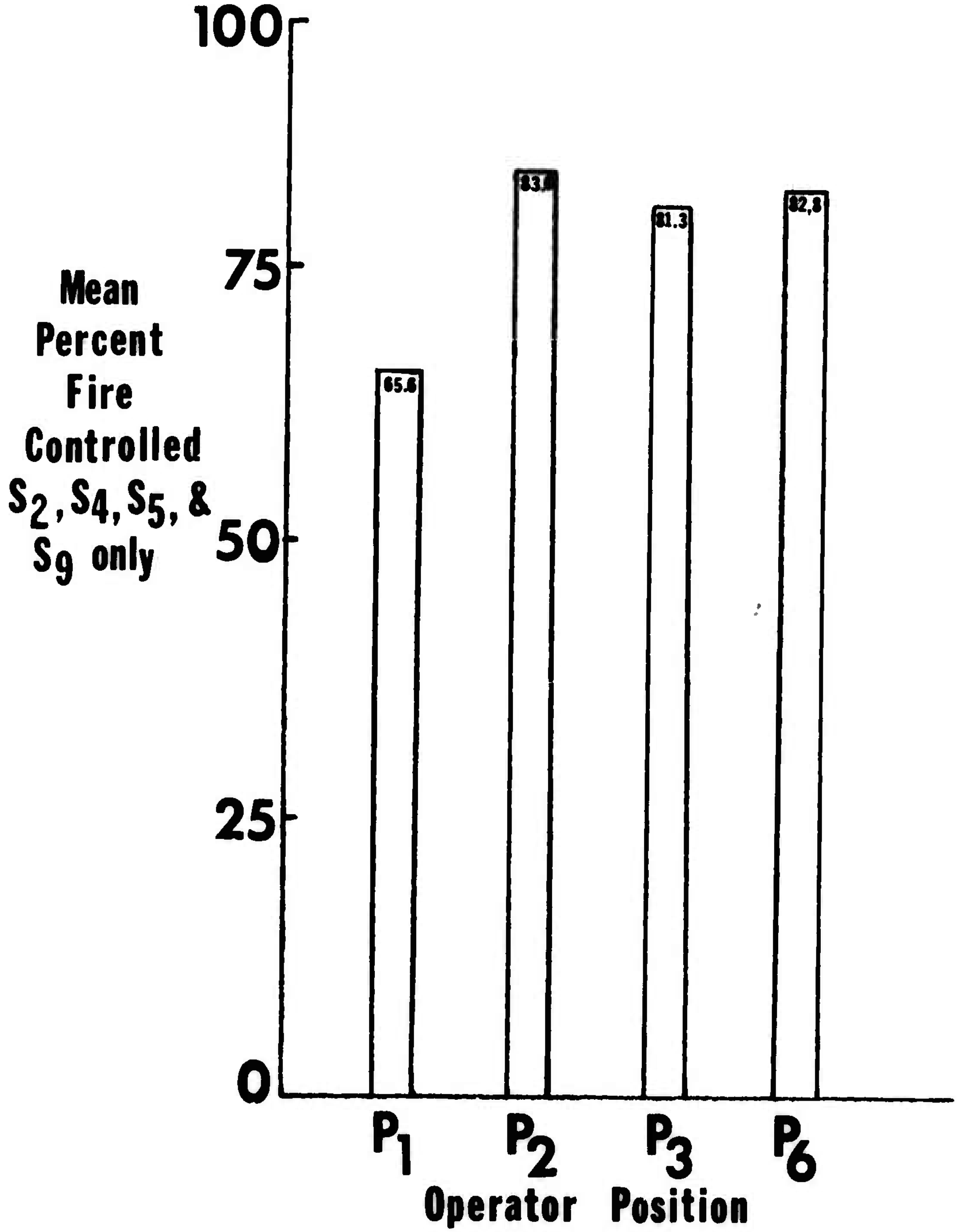

Figure 7: Phase II Performance

to see the stream and its impact point would lessen in importance. More aspects of turret control could then be made based only on turret controller position. However, both control systems used could not present such information via controller position. An operator could use controller position to estimate turret position on the standard turret and thereby have somewhat less need for visual feedback. However, accuracy and speed continued to suffer due to the operator effort required to change turret direction. An operator using the new turret controller could not easily use controller position as a cue to turret position. Hence, its effective use definitely required perceiving the stream and its impact point. In a fire situation such perceptions were obscurred. The advantages of the new system demonstrated in Phase I failed to appear in Phase II primarily due to such perceptual problems.

APPENDIX A

QUESTIONNAIRE

TURRET CONTROL SYSTEMS

P-4 FIRE TRUCK

DATE: ______________

TIME: ______________
(24 hour clock)

After each test operation involving either the ceiling mounted hydraulic assisted turret control (Standard) or the newly designed electrical turret control (Hand) please fill out the following questionnaire. "Standard" and one of those under "Hand". It is necessary that you make choices under both the "Standard" and the "Hand" headings after each question even though one will be made as a recent impression and the other from memory.

NAME:

GRADE: AFSC: Proficiency Level:

ARE YOU: Right Handed Left Handed
(Circle one)

HAND USED TO OPERATE CONTROL (Circle one): Right Left

TEST MONITOR: Please indicate the following by circling.

1. Was foam used?

   a. Yes
   b. No

2. Type of stream:

   a. Stream
   b. Dispersed
   c. Combination of both a and b

3. Type of fire:

   a. Fire
   b. No fire

4. Type of control:

   a. Hand
   b. Standard

5. Control location (Hand control only):

a. In cab
b. Out of cab

Please describe the fire situation including fire size, weather, and fire fighting approach.

6. How would you rate your abilities to survey the entire test situation based on the location of each control?

HAND	STANDARD
1. Extremely good	1. Extremely good
2. Good	2. Good
3. Fair	3. Fair
4. Poor	4. Poor
5. Very poor	5. Very poor

COMMENTS:

7. How would you rate the operating characteristics of each control handle?

HAND	STANDARD
1. Extremely easy	1. Extremely easy
2. Easy	2. Easy
3. Awkward, only in certain positions.	3. Awkward, only in certain positions.
4. Awkward	4. Awkward
5. Very awkward	5. Very awkward

COMMENTS:

8. How would you estimate the effort required to operate each control handle?

HAND	STANDARD
1. No effort	1. No effort
2. Modest effort	2. Modest effort
3. Difficult	3. Difficult
4. Extremely Difficult	4. Extremely Difficult

COMMENTS:

9. When operating each control handle during discharge how would you rate your ability to see the specific area of agent application?

HAND	STANDARD
1. Extremely good	1. Extremely good
2. Good	2. Good
3. Fair	3. Fair
4. Poor	4. Poor
5. Very poor	5. Very poor

COMMENTS:

10. When operating each control handle how would you rate your ability to move the stream into a designated 10' X 10' area which is located at the following points in relation to the cab? Answer only those segments where these area locations are within the field of operation. If locations are not applicable, so indicate (N.A.).

a. Near right (about 35')

HAND	STANDARD
1. Very good	1. Very good
2. Satisfactory	2. Satisfactory
3. Unable	3. Unable

COMMENTS:

b. Near front (about 35')

HAND	STANDARD
1. Very good	1. Very good
2. Satisfactory	2. Satisfactory
3. Unable	3. Unable

COMMENTS:

c. Near left (about 35')

HAND

1. Very good
2. Satisfactory
3. Unable

STANDARD

1. Very good
2. Satisfactory
3. Unable

COMMENTS:

d. Far right (about 100')

HAND

1. Very good
2. Satisfactory
3. Unable

STANDARD

1. Very good
2. Satisfactory
3. Unable

COMMENTS:

e. Far front (about 100')

HAND

1. Very good
2. Satisfactory
3. Unable

STANDARD

1. Very good
2. Satisfactory
3. Unable

COMMENTS:

f. Far left (about 100')

HAND

1. Very good
2. Satisfactory
3. Unable

STANDARD

1. Very good
2. Satisfactory
3. Unable

COMMENTS:

11. Assuming that the hand control system panel would include dispersion controls, stream selector, single vs double barrel selector, and an on-off switch all of which operate equally as well as those located on the standard system, rate each control system for operating use only.

HAND

Unusable Fair Excellent

STANDARD

Unusable Fair Excellent

Why?

12. Additional Comments:

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